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VISION AND THE TECHNIQUE OF ART.

By A. Ames, Jr., C. A. Proctor and Blanche Ames.

Investigations on Light and Heat, published with aid from the Rumford Fund.

(Continued from page 3 of cover.)

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CONTENTS.

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Presented by Louis Bell.

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INTRODUCTORY.

There are many well known instances where very successful use has been made by artists of certain of the laws of vision as a basis of technique. The "pointillist" technique of Pissaro and Monet is probably the best example.

The artist Birge Harrison [1] has gone farthest towards recognizing the dependency of the technique of art on the laws of vision. He most forcefully and lucidly shows that a picture in its general form should be similar to our retinal impressions. Mr. Ames and his sister, Blanche Ames, who were painting together came to a similar conviction in 1912. Attempts were made to paint pictures of this nature. The difficulty of analyzing the character of images of objects upon which the eye was not focused was at once encountered. This is without doubt due to the universal and probably immemorial human practice of looking directly at, i.e., focusing upon anything we desire to judge or analyze. Mr. Ames therefore undertook to determine scientifically the characteristics of the images of those objects upon which the eye is not focused in the belief that an intellectual conception of the characteristics of such images would help in the visual recognition and analysis of them, and thus be an aid in the technique of art.

He thought that the desired information could be obtained in a few weeks — at most a few months. The scientific data upon which such information is based, however, had not been worked out. This necessitated research work upon which he has been occupied up to the present. The data collected, although representing a considerable advance, constitute hardly more than the preliminary steps towards definitely determining the characteristics of the retinal

[1] "Landscape Painting" by Birge Harrison. Charles Scribner's Sons.

picture. Most of the data has been published in a paper by Mr. Ames and Dr. C. A. Proctor, entitled "Dioptrics of the Eye." [2]

It is the purpose of the present paper to convey as clear an understanding as possible of the nature of the retinal picture and to point out conclusions to which such an understanding leads us.

PREFACE.

A consideration of the analogy between our eye and a photographic camera is helpful for a general understanding of the subject.

Broadly speaking the eye is like a camera, or more truly speaking cameras were made like the eye, the lens of the camera corresponding to the lens of the eye and the plate or film to the retina. As the character of a photograph depends upon the kind of lens and plate used, so the characteristics of our retinal picture depend first upon the nature of the lens of the eye and second upon the nature and sensitivity of the nerve structure, i.e., the retina upon which the image is formed.

Certain photographic lenses are corrected.[3] The detail in photographs taken with such lenses is clear and distinct over the entire picture and free from distortion. Other photographic lenses which are not corrected produce pictures in which the detail is indistinct and distorted in varying degrees.

The lens system of the eye is not corrected. The details in part of the image formed by it are clear, in other parts unclear and all more or less distorted.

Furthermore, the retina, instead of being equally sensitive over its entire area as is a photographic plate, varies in sensitiveness in different parts.

As a result of the effects of the lens system of the eye and the effects of the variable sensitivity of the retina the retinal picture has characteristics which make it markedly different from photographs taken

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[2] Journal Opt. Soc. of Amer., Vol. V, Jan. 1921.

[3] The image of a scene formed by a simple lens (called uncorrected), such as a spectacle lens or a magnifying glass, is not an exact reproduction of the scene itself. The detail of objects at the center of the picture is slightly softened and has chromatic edges. The detail at the sides of the picture is still more softened and objects at the side are bent and distorted.

To make the detail at the center as well as at the sides perfectly sharp and to do away with distortion, so called corrected lenses were devised. They consist of a combination of two or more simple lenses of determined character and separation.

with a corrected lens or even with an uncorrected lens. For though the eye has an uncorrected lens, the lack of corrections, so to speak, is markedly different from that existing in any known uncorrected photographic lens, and so produces a different effect.

To give an understanding of the more specific characteristics of the retinal picture it is necessary to take up and describe the characteristics of the images formed of objects in different parts of the field of view, i.e., the scene at which we are looking.

We shall take up the images of objects in the various parts of the field of view in the following order: First, the images of objects at which the eye is directly looking, or, in other words, those objects which lie in the line of vision and which are in sharp focus. See A, Figure 1. This will be covered in Chapter I, Distinct Vision.

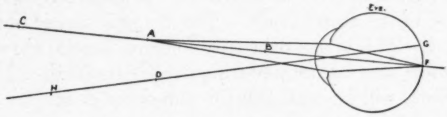

FIGURE 1. Diagram showing positions of various objects in the field of view. F B A C is the axes of vision or line of sight along which the eye is looking. A is the object on which the eye is focused. It will be imaged sharply on the fovea F. B and C are points on the line of sight inside and outside the point of focus. D is an object to one side of the line of sight. It will be imaged on the peripheral part of the retina at G.

Second, the images of objects which are on the line of vision nearer and farther away than the object in focus (see B and C, Figure 1); Chapter II, Depth of Field Axial.

Third, the images of objects which are not in the direct line of vision as D, Figure 1. These images will be described in Chapters III, IV and V.

Chapter III, Depth of Field (Lateral), will deal with the characteristic imaging of objects not in the direct line of vision and at different distances from the eye. See D and H, Figure 1.

Chapter IV, Distortion in Form, will deal with the distortion of the images of objects not in the direct line of vision.

Chapter V, Peripheral Color Sensitivity, will deal with the change in the local color of images of objects not in the direct line of vision.

In Chapter VI the effect of binocular vision will be considered in a general way.

In Chapter VII the results will be summarized and discussed.

Chapter I.

DISTINCT VISION.

Distinct vision deals with the nature of retinal images of objects at which the eye is looking directly, i.e., that are in sharp focus. As we have a very definite conception of the appearance of objects at which we look directly it may hardly seem necessary to analyze the characteristics of the images of such objects. It is believed however that such an analysis will not only be instructive but will make it easier to understand the characteristics of the images of objects upon which the eye is not focused, which will be taken up later.

Owing to the nature of the lens system of the eye the image on the retina formed by an object at which the eye is directly looking is not an exact copy of the object itself. The image is spread out and somewhat diffused. This is due primarily to three factors; chromatic aberration; spherical aberration; and irregular astigmatism. These factors and their effects will be considered in the order given.

CHROMATIC ABERRATION.

Chromatic aberration causes light of different wave length or color to come to focus at different distances behind the lens, light of shorter wave length, i.e., towards the blue end of the spectrum focusing nearer the lens. This is shown in Figure 2.

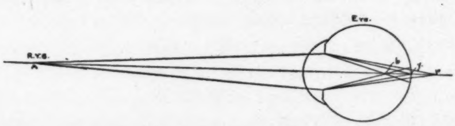

Figure 2. Diagram showing chromatic aberration of the eye.

If we have three point sources of light at A, one red, one yellow, and one blue, the image of the blue source will be formed at (b) the image of the yellow source at (y), while the red image will be at (r). Figure 3 shows the shape of image bundles as formed in Mr. Ames' eye by point sources of red, yellow and blue light. These of course are much enlarged; the lens system of the eye is to the left.

It will be seen that the blue bundle lies to the left or nearer the lens

than the yellow bundle and that the yellow bundle lies to the left of the red.

The eye normally focuses for yellow light, i.e., so that the small cross section of the yellow bundle falls on the retina. If the eye looks at red, yellow, and blue point sources at the same time the retina would be in the position relative to the three bundles as shown in Figure 3. It will be noted that the smallest cross section of the blue bundle lies in front of the retina, that of the red behind.

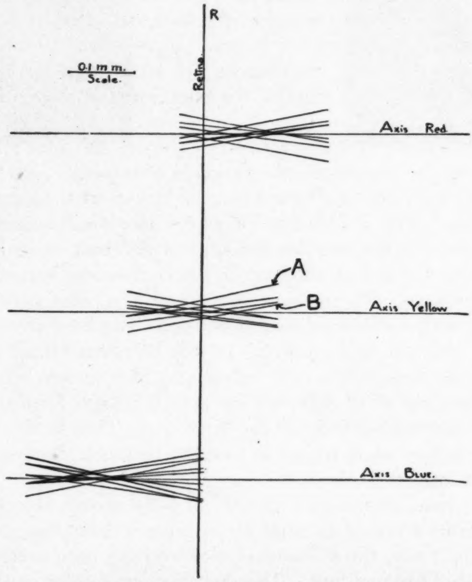

FIGURE 3. Image bundles formed by light from red, yellow, and blue point sources. Their displacement right and left shows the Chromatic Aberration of the eye. The different distances from the retina at which the individual rays, in each bundle, cut the axis shows the Spherical Aberration.

It will also be noted that where the red and blue bundles cut the retina they are much larger in diameter than the yellow bundle. This is also shown in Figure 4 which is a photograph of the magnified image of a point source of white light taken with a lens which has approximately the same chromatic aberration as the eye. A white light source is composed of light of all wave lengths. The camera was focused to

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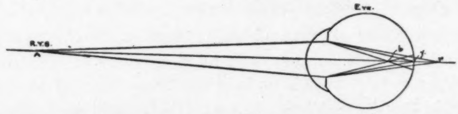

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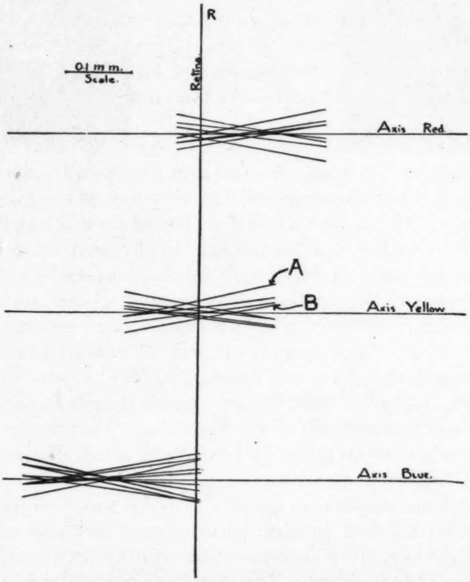

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It will also be noted that where the red and blue bundles cut the retina they are much larger in diameter than the yellow bundle. This is also shown in Figure 4 which is a photograph of the magnified image of a point source of white light taken with a lens which has approximately the same chromatic aberration as the eye. A white light source is composed of light of all wave lengths. The camera was focused to

get as sharp an image as possible of the yellow light and then the three pictures were taken, the top one through a red screen, the middle one through a yellow,[4] the lower one through a blue. The top photograph therefore shows the image formed by the red rays in the white light source, the middle one that formed by the yellow rays, and the bottom one that formed by the blue rays.

Colored images of the same relative difference in size are apparent to the eye looking at a point source through monochromatic screens or filters if the eye is kept focused for yellow. Without any screens or filters the eye receives an image of the nature obtained by combining the three images in Figure 4. It would have a bright center tending towards yellow in color, surrounded by larger and larger rings of shorter and longer wave lengths, the blue rings extending out farther than the red.

A comparison of the image formed by the eye and that formed by a lens corrected for chromatic aberration is of interest. Such a lens is designed so that light of all wave lengths focuses at the same distance from the lens. This is shown in Figure 5 where it will be seen that the narrowest part of the bundles for light of different wave length, instead of being focused at different distances from the lens, all focus at the same distance. Figure 6 is a photograph of a point source of white light taken with a corrected lens. The photographs were made in the same way as those in Figure 4. It will be noticed that where the images taken through the red, yellow and blue screens with the uncorrected lens are all of different size similar images formed by a corrected lens are substantially all the same size. That is, this correction causes the images of an object in focus to be much sharper or clearer than those formed in the eye.

We have been speaking so far only of point source objects. If the object is either a line or an edge, for instance a dark edge of a window against a light sky, the diffusion circles we have been describing take the form of diffusion edges. The distribution of color in these diffusion edges follows the same laws as govern that in the diffusion circles. This is shown clearly in Figure 7, which is a photograph taken through a lens having approximately the same chromatic aberration as the eye,

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[4] As the filters actually used in taking this and following pictures were Eastman Kodak Co. films Red No. 25, Green No. 58 and Blue No. 48, it would be more exact to use the word "green" instead of "yellow." The difference in wave length between the green and yellow however is such that there would be no appreciable differences in the appearance of the photographs whether a green or yellow filter was used. The term yellow will therefore be used for sake of simplicity and clearness.

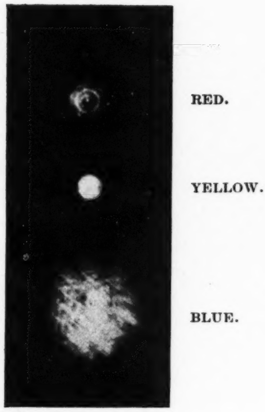


Fig. 4.

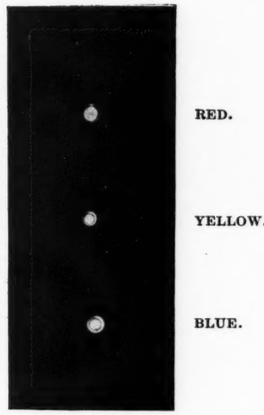


Fig. 6.

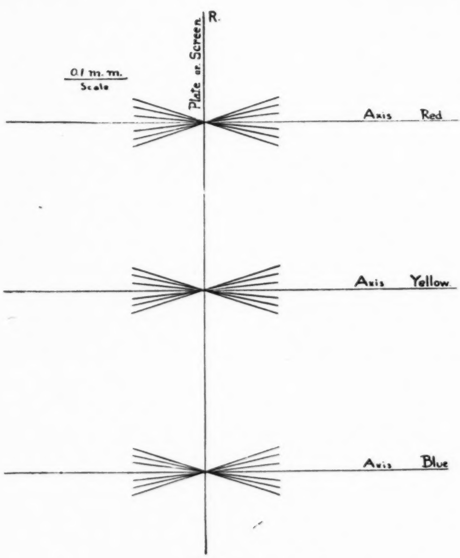


Fig. 5.

FIGURE 4. Three color photograph of a white light point source taken with lens having same chromatic aberration as the eye. Magnification 110 diameters.

FIGURE 5. Image bundles which would be formed by light from red, yellow and blue point sources passing through a lens perfectly corrected for chromatic and spherical aberration.

FIGURE 6. Three color photograph of a white light point source with a lens corrected for chromatic aberration. Magnification 110 diameters.

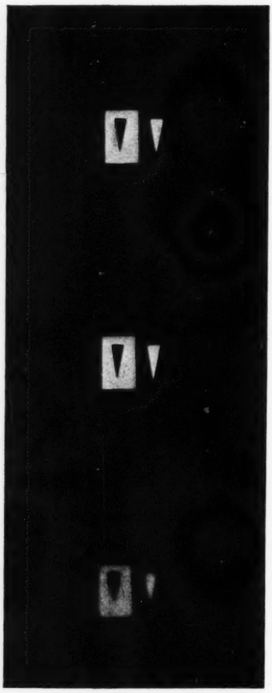


Fig. 7.

RED

YELLOW.

BLUE.

Fig. 8.

FIGURE 7. Three color photograph of black and white wedges taken with lens having the same chromatic aberration as the eye. The base of the wedges which were about six feet distant measured $\frac{1}{4}$ inch.

FIGURE 8. Same as Figure 7 taken with a lens corrected for chromatic aberration.

of a white wedge on a black background and a black wedge on a white background. The base of the wedges was one-fourth inch and their distance six feet from the camera.

The top picture was taken through a red, the middle through a yellow, and the bottom one through a blue filter. The camera was focused to give a sharp image with the yellow filter. The top picture shows the kind of image that is formed on the retina by the red light, the middle one the kind of image that is formed by the yellow light and the bottom one the kind of image that is formed by the blue light. If you imagine these superimposed, which is what takes place on the retina, the combined picture will have a blue diffused edge extending over the black and a less wide red edge. The color of the white near the edges will be slightly yellowish due to the subtraction of the blue and red.

With a lens free from chromatic aberration no such effect is produced. This is shown by Figure 8, which is a photograph of the same objects taken at the same distance and in the same way, with a corrected lens. The images of all the wedges in this case are sharp and clear and of the same size. They will all exactly superimpose and no chromatic edges will be formed.

Under ordinary circumstances unless the attention is especially called to them these chromatic rings and edges formed in the eye are not seen. This is due, it is believed, partly to the fact that the red rings overlie the green, which being complementary colors form white light, and to the fact that the blue is so spread out that it is relatively weak. However, if one looks carefully for these rings or edges they can be seen around an arc light at night, in the blue haze or halo on the dark background.

The red and blue chromatic circles or edges can be seen separately by looking at a dark object, such as a window sash against a bright sky at a distance of three to six feet and shutting off the light from half the pupil by passing a card or piece of paper close to the eye, the edge of the paper being kept parallel to the window sash. One side of the frame will have a red orange edge, the other a bluish edge. If the card is brought in from the other direction the color of the edges will reverse. Without the card the colors overlie each other and become much less visible for the reason given above. However, once the phenomenon has been noticed a soft floating purplish edge becomes apparent even without the card.

A very striking example of chromatic aberration, and one which gives a very good idea of its magnitude, is apparent when one looks

at the purple railroad switch lamps used, for example, by the Boston and Albany Railroad. At close range these lamps appear purple, but as one moves away the light appears to have a red center surrounded by a blue disk or halo; the farther off one goes the larger the blue halo appears.

SPHERICAL ABERRATION.

Another factor that has a bearing on the nature of the retinal image of an object on which the eye is focused is the spherical aberration mentioned above. In a lens free from spherical aberration the rays that come through different zones of the lens, for example those that come through the lens near its center and near its edge, all focus down to a point. This is shown in Figure 5 where rays near the outside of the cone and those near its center all go through one point at the apex of the cone. In a lens which has spherical aberration this is not true. The rays from different zones of the lens do not pass through the same point. This is shown in Figure 3, where it will be seen that ray A, for instance, crosses the axis far to the left of ray B. Due to this fact the image of a point source formed in the eye will be larger and with softer edges than that formed by a corrected lens.

IRREGULAR ASTIGMATISM.

There is still another factor that has a bearing on the nature of retinal images of an object on which the eye is focused. That is irregular astigmatism. This term covers all irregularities in the shape and distribution of light in the image due to such things as opaque substances or irregularities of densities in the lens system. A most marked example of this factor is the star shape appearance, known to everyone, of a small source of light. If the eye were not subject to irregular astigmatism of some sort the image of a small source, though it might be affected by chromatic and spherical aberration, would be circular. Such retinal images, however, are always star shaped.

SUMMARY.

The three aforementioned factors, chromatic aberration, spherical aberration, and irregular astigmatism, cause the retinal image of an object upon which the eye is focused to have a characteristic appearance both as to the amount of detail which is visible and in the appearance of all edges.

From the point of view of the technique of art the question arises is it necessary that these characteristics be reproduced in the depicting of an object upon which the eye is focused?

The care used by the better artists to paint broadly, i.e., not to get, even in the most detailed parts of their pictures, any more detail than is apparent to them at the distance at which they stand from their model or scene and their quite common practice of softening and treating their edges, is evidence that to be technically satisfactory from an artistic point of view the detail of an object on which the eye is focused should be depicted with the same characteristics with which it is imaged upon the retina. This evidence is further supported by the fact, as will be shown later, that the characteristics of the images of objects upon which the eye is not focused, must be reproduced to bring out the appearance of depth and to make the pictures pleasing.

Chapter II.

DEPTH OF FIELD (AXIAL).

In this chapter we will deal with the nature of images of objects that are in the line of vision nearer and farther away from the observer than the object upon which the eye is focused.

The images of such objects will have markedly different characteristics from those of objects in focus.

These characteristic differences are due primarily to two factors. First, Depth of Field of the lens system; second, Chromatic Aberration.

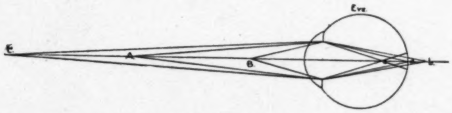


Figure 9. Diagram showing diffusion of images of point source objects not in focus.

DEPTH OF FIELD.

For sake of brevity and simplicity a full explanation of Depth of Field will not be gone into. It is evident however that an object which lies nearer or farther from the observer than the object upon which he is focused will be imaged not on the retina but behind it or in front of it. This is shown in Figure 9.

The image of point source object A upon which the eye is focused is imaged on the retina at (a), that of B behind the retina at (b), that of C in front of the retina at (c). Where the image bundle which forms the image (b) cuts the retina it is a cone of considerable size. The object B will appear as a diffusion circle. The image bundle which focuses down to the image C in front of the retina is spread out again and also appears as a diffusion circle. If instead of a point source the objects at B and C are objects with edges the edges will have the well known appearance that is seen on an object that is out of focus, i.e., a pencil held near the eye while the eye is focused on a distant object. The nearer the objects B and C approach A the smaller will be the size of these diffusion circles and the more similar all their images become. The magnitude of this effect depends upon the focal length of the lens system and the size of the aperture. In the eye this means, broadly speaking, the length of the eye and the size of the pupil. It is very marked where either the objects in or out of focus are close to the eye but decreases as they are moved away and becomes imperceptible when they all are at a distance of thirty feet or more.

CHROMATIC ABERRATION.

As was described in Chapter I the effect of chromatic aberration is to cause light of different wave length or color to focus at different distances from the lens. See Figure 2.

If we move the blue point source at A, Figure 2, towards the eye, the eye being kept focused on A, it will cause the image of the blue source to move back towards the retina. A position B, Figure 10, will be found where a blue light will focus sharply on the retina while the eye is still focused on the point at A. If we move the red light away from the eye a similar position R, Figure 10, will be found where the red light will also be in focus.

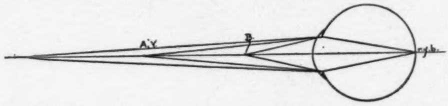


FIGURE 10. Diagram showing how images from sources of different colors situated at different distances from the eye can all be in focus at the same time.

That is all three lights will be in focus at the same time although they are at very different distances from the eye. For example if the eye is focused on a yellow light at a distance of six feet it will see

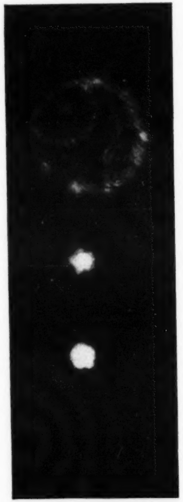


Fig. 11.

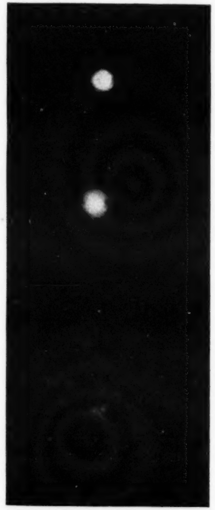


Fig. 12.

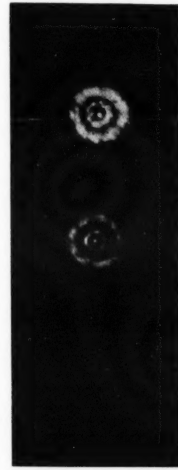


Fig. 13.

Fig. 14.

FIGURE 11. Three color photograph of a white light point source taken with a lens having the same chromatic aberration as the eye. The lens was focused on an object six feet away. The light source was three feet away. Magnification 110 diameters.

FIGURE 12. Same as Figure 11 except that the light source was eighteen feet away.

FIGURE 13. Same as Figure 11 taken with a lens corrected for chromatic aberration.

FIGURE 14. Same as Figure 12 taken with a lens corrected for chromatic aberration.

sharply at the same time a blue light about three feet away and a red light at about twenty feet away.

We described in Chapter I the characteristic chromatic diffusion circles and edges of an object in focus. We saw that a white light point source as at A, Figure 10, would form an image with a yellowish center surrounded by red and blue diffusion circles. A white light point source at B, Figure 10, however, will form quite a different image. The blue in the white light being in focus will, as we have just shown, form a sharp image. The yellow will be out of focus and form a yellow diffusion circle around the blue and the red will be still more out of focus and form a larger red diffusion circle which will extend outside that of the yellow.

Figure 11, is a photograph of a point source of white light taken with a lens which has approximately the same chromatic aberration as the eye. The lens was focused to give a sharp image of the yellow rays in a white light source about six feet away. The pictures are of a white light point source about three feet away. As in Figure 4 the top image was taken through a red, the middle one through a yellow, and the bottom one through a blue filter. The combined image which is the appearance the white light point source would have to the eye is markedly different from that shown in Figure 4.

A white light point source at R, Figure 10, will form a still different kind of image. The red in the white light being in focus will form a sharp image. The yellow will be out of focus and form a yellow diffusion circle around the red and the blue being still more out of focus will form a larger blue diffusion circle.

Figure 12 is a photograph similar to those described in Figure 4 and Figure 11, but with the objects twenty feet away. The images formed are very different from those shown in Figure 4 and 11.

Images of white light point sources situated at other distances along the axis will vary from those shown above, their characteristics depending on the position of the fixation point and their distance from it.

A lens corrected for chromatic aberration forms very different images of similar white light point sources. Figures 13 and 14 are photographs taken with a corrected lens. The photographs were made in the same way as those shown in Figures 11 and 12 of white light point sources in similar positions. As the point in the focus of a corrected lens is in focus for all colors so a point out of focus is out of focus for all colors and to the same extent. The diffusion circles for red, yellow and blue light in Figures 13 and 14 are therefore all about the same size. The combined image although enlarged and fuzzy will

appear white, i.e., without colored edges, no matter in what direction or distance the white light point source is from the point in focus.

As described in Chapter I if instead of a point source edges are used, as a dark object against a light background, the above described diffusions make themselves evident in the form of chromatic edges.

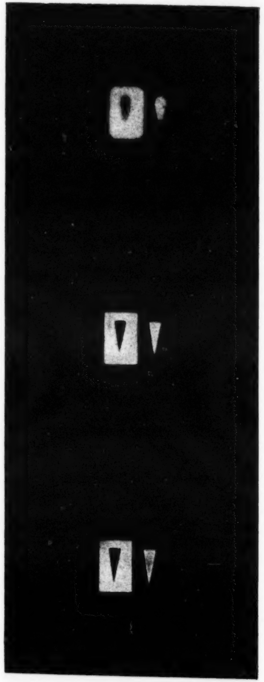
Figure 15 shows a photograph taken with a lens, which has approximately the same chromatic aberration as the eye, in the same way and of the same objects as described in Figure 7. The lens was focused as described for Figure 11 for yellow at six feet, the objects being three feet away. The combined images are marked by the orange red edges extending over the dark and the blueness of the white along its edges due to the subtraction of the red and yellow light which has diffused over the black.

Figure 16 is a similar photograph, the focus of the lens remaining the same, the objects being placed at a distance of about twenty feet. In this case the combined images are characterized by the green and blue extending over the dark and the redness of the white along its edges.

It is regretted extremely that these pictures cannot be reproduced in color as they not only show these characteristics much more clearly, but are very beautiful.

Figure 17 is similar to Figure 15 taken with a corrected lens. As would be expected from what has been said of Figures 13 and 14 the images taken through the different filters are all diffused to the same extent. As a result the composite picture shows diffused but no colored edges.

Once one's attention has been called to them, these characteristic chromatic edges in the retinal images are very easily seen. The aberration of the red rays over the dark, characteristic of images of objects which lie inside the focus, was first noticed in the warm color of black specks on a windowpane viewed from a few feet when the eye is focused on the distant sky. All of the characteristic colored edges can be easily seen with the following arrangement. Against the white wall of a room or a piece of cardboard or sheeting put up at the distance of about twenty feet a black object, preferably one that comes down to fine black points, as iron grill work, black wedges of paper will do. At six feet distance put up any small object to focus on in line with the distant objects. At three feet distance in the same line put up another black object preferably like the first. If the eye is kept focused on the object at six feet the dark edges of the near object appear to have a reddish orange tinge next to which the light appears colder or bluer. The edges of the object at twenty feet, in fact the whole surface if the



RED.

YELLOW.

BLUE.

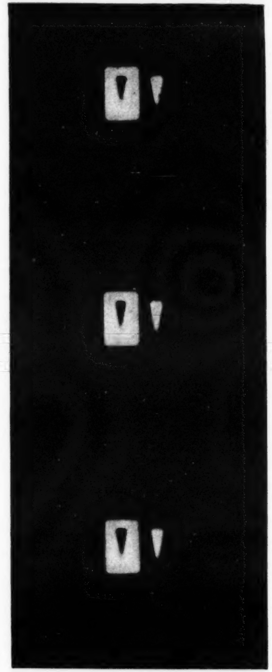
Fig. 15.

RED.

YELLOW.

BLUE.

Fig. 16.



RED.

YELLOW.

BLUE.

Fig. 17.

FIGURE 15. Three color photograph of black and white wedges taken with lens having same chromatic aberration as the eye. The lens was focused on an object six feet away, the wedges were three feet away. Width of base of wedges $\frac{1}{8}$ inch.
FIGURE 16. Same as Figure 15 except that wedges were eighteen feet away. Width of base of wedges $\frac{3}{4}$ inch.
FIGURE 17. Same as Figure 15 taken with a lens corrected for chromatic aberration.

Fig. 17a — No. 1.

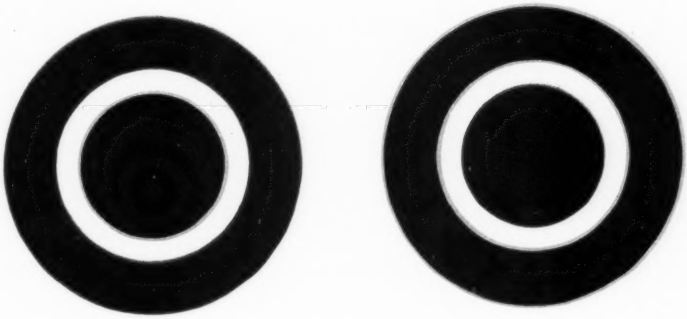


Fig. 17a — No. 2.

dark objects are narrow enough, appear very bluish while the lights next to the dark objects appear pale orange. Of course if the focus of the eye is not kept fixed on the central object these appearances will not be visible for they only exist on objects that are not in focus. It may take some practice to keep from changing the focus as the natural tendency is to focus upon the object which one is trying to analyze.

The colored edges on both far and near objects are best seen when the objects are at the relative distances above described. Red edges on the dark become more evident with a more distant fixation and blue on the dark with a nearer one.

Where both the fixation and the nearer object are twenty feet or more away both objects are so nearly in the same focus that the difference in colored edges is hard to distinguish.

These facts lead naturally to the assumption that with a given fixation the characteristic colored edges of objects nearer and farther than the fixation object inform us of their relative distance, that is, if an object has red edges we judge it to be nearer to us than the fixation object while if it has blue objects we judge it to be farther away. If this is so objects depicted in a picture with red edges should appear nearer than those with blue edges. This is exactly what was found to be the case as is shown by Figure 17a. It will be seen that the circles with the reddish edges appear to be on a nearer plane than those with the blue edges.[5]

SUMMARY.

The effect of depth of focus which produces the fuzzy edges of objects nearer or farther than the object plane has been long recognized in photography.

This is shown in the photographs in Figures 18 and 19. That in Figure 18 was taken with a small aperture, F 16, which causes objects at all distances to be imaged sharply, while that in Figure 19 was taken with a large aperture, F 4.5, which causes objects nearer and farther than the focus point to the imaged with a greater softening of edge. The greater effect of depth in the photograph in Figure 19 as compared with that in Figure 18 is very evident.

Gleichen [6] goes into the subject at length and points out that a

---

[5] The illusion is more apparent if one eye is closed. This prevents the functioning of our binocular depth perception by which we tend to recognize the true distance of both figures.

[6] "Die Grundgesetze der naturgetreuen photographischen Abbildung." Halle 1910. "Uber Helligkeit und Tiefe inbesondere bei der naturgetreuen Photographischen Abbildung." Zeit, fur Wiss. Phot. Vol. 9, 1911, p. 241.

natural effect of depth can only be produced by a lens which has the same depth of field as the eye.

He does not, however, deal with the effects of chromatic aberration. The depth effect due to it is believed to be much more marked than that due to simple depth of field.

In simple depth of field the diffusion of edge due to an object being out of focus gives no indication as to whether the object is nearer or farther than the focus point. Chromatic aberration on the other hand causes objects beyond the focus point to be imaged in a characteristically different way from those inside. This in turn gives a real basis for monocular depth perception apart from the relative sizes of objects or disappearing or other perspective. As shown by Figure 17a this effect of depth can be obtained in a picture if the objects are depicted with their characteristic chromatic edges. A marked effect of depth has thus been obtained in pictures painted by Blanche Ames.

Many paintings by great masters have been looked at to find whether this characteristic edging has been made use of. The treating of edges as stated before is quite common, and in certain paintings, by Millet for instance, warm or reddish edges are found around near objects while objects in the distance are colder and bluer. It is not felt, however, that the evidence is sufficient to conclude that it has been used consistently.

Chapter III.

DEPTH OF FIELD (LATERAL).

In this chapter we will deal with the characteristics of images of objects which are situated not on the line of vision. The characteristic form of such images is due primarily to an aberration called oblique astigmatism. (This should not be confused with corneal astigmatism.)

Oblique astigmatism causes the rays of light, from a point source not on the axis, to focus into a ray bundle of complex form. As explained above the ray bundle from a point source on the axis focuses in the form of a cone to a point where the rays cross to spread out into another cone. The ray bundle from a point source not on the axis forms a more complicated figure. In its pure form in a simple uncorrected lens it focuses first to a line, see aa, Figure 22, which lies in a position tangential to a circle about the axis of the lens. It then crosses and narrows in its long dimension and lengthens in its short

FIGURE 18. Photograph taken with a small aperture, i.e. F 16.

FIGURE 19. Same view as in Figure 18 taken with a large aperture, i.e. F 4.5.

one until it becomes a line again, see bb, Figure 22, which is perpendicular to the first line.

The image of every point source not on the axis has this peculiar form. The farther the source from the axis the greater the separation between the two parts of the image which have the form of lines. If a sensitive plate or ground glass screen is placed behind the lens the form of the image that is apparent depends upon the position of the screen. If it is placed far back, i.e., to the left of bb, Figure 22, the image will be in the form of a radial oval, i.e., radial to a circle about the axis of vision, in the horizontal plane this would be horizontal; if at bb, in the form of a radial line; if half way between aa and bb, the form of a circle; if at aa, the form of a tangential line, i.e., tangential a circle about to the axis of vision, in the horizontal plan this would be vertical; if still nearer the lens, in the form of a tangential oval. If the screen is held stationary relative to the lens, a similar

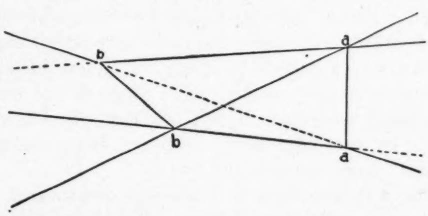


FIGURE 22. Diagram showing characteristic shape of the image bundle of a point source not on the axis.

change in form of image can be noted by moving the point source from a distance to a position near the lens, always keeping it at the same angular obliquity.

If, instead of a point, a line source is used, a similar imaging takes place. Every point on the line source is stretched tangentially or radially, depending upon the position of the line source. It can be seen that if the stretching of the various parts of the line source is along the length of the line source itself, the image of the line will appear perfectly sharp and slightly elongated. That is, if a line source is tangential to the axis, its image will be sharp when the source is so positioned that the part of the image that forms a tangential line, i.e., aa, Figure 22, falls on the screen. If it is in a position radial to the axis, its image will be sharp when that part of its image that forms a radial line falls on the screen.

In all simple lenses this characteristic image formation is more or less confused by coma, a one-sided blur, and by chromatic aberrations. The magnitude of these aberrations in the eye has not yet been measured.

This may all be made a little clearer by a brief description of how Mr. Ames measured the oblique astigmatism in his own eye. A point in space is fixated with one eye, i.e., by focusing on a point of light, the line of vision and the focus of the eye is not allowed to vary. At one side of the line of vision (at an angle of obliquity of five degrees), three narrow tangential lines (in this case vertical) of yellow light were moved back and forth. It was found that when these lines were at a certain distance they could be distinguished as separate. At any other distance they could not be distinguished. The distance at which they could be distinguished was such as to cause that part of the image designated as aa, Figure 22, to fall on the retina which made the tangential lines appear most sharp. This point was found to be nearer than the fixation point. Similar points were found at varying degrees of obliquity from the axis where the three narrow lines appeared most sharp. In this way a surface in space was determined where yellow tangential lines were most visible. The shape of this surface which is called the primary astigmatic object field for yellow is shown in plan on Figure 23 by the solid lines extending from the point marked "fixation point" back towards the eye.

In the same way a surface in space was determined where yellow radial lines were most visible. This is called the secondary astigmatic object field for yellow and is shown in plan by the dotted lines extended in shape of a ram's horns from the point marked "fixation point" outward. Figure 23.

Corresponding fields for red, blue and green monochromatic light were found and are shown in Figure 23.

If this fixation point is changed although these primary and secondary astigmatic object fields keep their general shape they shift forward and backward.

Heinrich [7] made a similar experiment with a black thread. He moved a black vertical thread (as he worked in a horizontal plane this would be a tangential line) which was placed to one side of the line of vision, back and forward until it appeared most like the thread on which the eye was fixiated. He found a field similar in shape and position to that which the writer found for the primary astigmatic field for yellow.

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[7] British Journal of Psych., Vol. 3, p. 66.

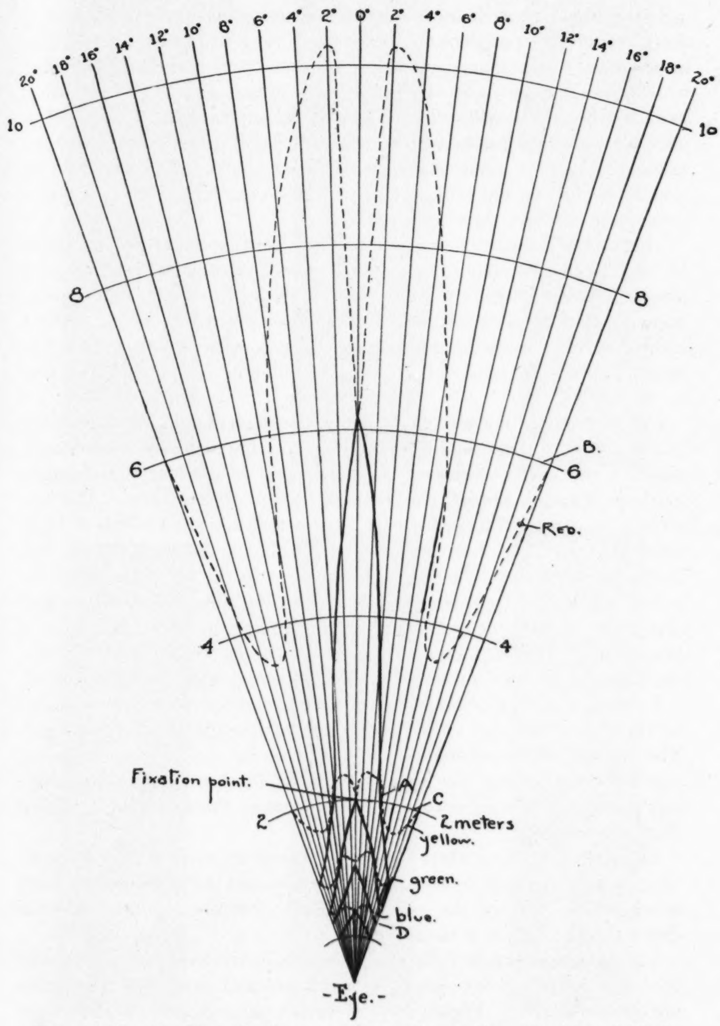


FIGURE 23. Position of primary and secondary astigmatic object fields for different colors.

This means that with any given fixation, at a given angle of obliquity, there are certain positions in space where tangential black and white lines appear most sharp and other positions where radial black and white lines appear most sharp. It also means that with the same fixation there are still other positions where tangential lines of a particular color will appear most sharp and still other positions where radial lines of the same color appear most sharp. The positions in space therefore where tangential and radial colored lines appear most sharp depend upon their color.

The different position of the primary and secondary astigmatic fields for different colors has a further effect of causing the images of black and white objects to have characteristic chromatic edges due to their position in space relative to the fixation point. This can be best shown by the following photographs taken with a lens which has approximately the same oblique astigmatism and chromatic aberration as the eye.

Figure 24 (b) is of a white light point source situated at C, Figure 23, i.e., in the secondary field for yellow at an angular obliquity of about eighteen or twenty degrees. As the lens is focused at the distance marked "fixation point" this is in the plane of the focus. The top picture shows the image formed by the red rays in the white light source; the middle that formed by the yellow; the bottom one that formed by the blue. As the point source is in the secondary field for yellow the yellow light is stretched in a radial direction. Being near the primary field for red the red is beginning to be stretched in a tangential direction. And being beyond the secondary field for blue the blue is stretched in a radial direction forming a diffused radial oval.

Figure 24 (a) is a photograph of a white light point source situated at B; Figure 23, i.e., in the secondary astigmatic field of red light. The red light is therefore stretched in a radial direction. The point source being beyond the secondary fields for both yellow and blue light they are imaged as diffused radial ovals, the blue more diffused than the yellow.

Figure 24 (c) is of a white light point source situated at D, Figure 23, i.e., near the primary field of red and yellow and the secondary of blue, consequently we see the red and yellow stretched in a tangential direction, the blue in a radial one.

The images of white light point sources in similar positions formed by a lens corrected for oblique astigmatism and chromatic aberration are quite different. Figure 24 (e) is such a photograph of a white light point source at C, Figure 23, i.e., in the plane of the focus. The lens

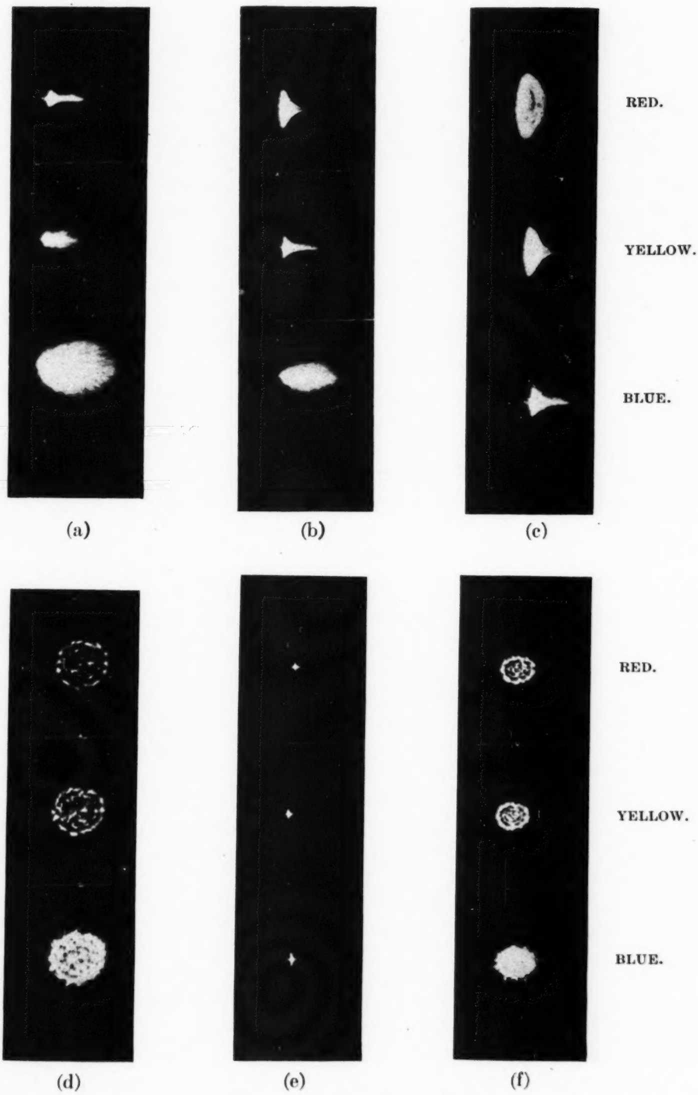


FIGURE 24. Three color photographs showing characteristic image forms of white light point sources at different distances. (a) (b) and (c) were taken with a lens having approximately the same chromatic aberration and astigmatism as the eye. (d) (e) and (f) were taken with the sources at the same distances with a corrected lens. Magnification 28 diameters.

being corrected for oblique astigmatism means that the image lines aa and bb, Figure 22, are brought together to a point on the image plane. There is therefore none of the characteristic stretching in tangential and radial directions which was so evident in the oblique images formed by the other lens. The lens also being corrected for chromatic aberration there is no substantial difference in the form of the images for the different colors. They are all imaged as small spots of light of about the same size. The marked difference in imaging from that which occurs in the eye as shown in Figure 24 (b) should be noted.

Figure 24 (d) and (f) are photographs made with a corrected lens of white light point sources at B and D, Figure 23. Due to the corrections the images do not show any stretching in a radial or tangential direction and they are all the same shape and size for different colors. The combined images will therefore appear simply as diffused white spots. The marked difference between this imaging and that shown in Figure 24 (a) and (c) should be noted.

It should also be noted here, that while in the imaging of point sources by the lens having substantially the same aberrations as the eye the images have characteristic forms and colored fringes due to their distances from the lens, in the imaging by the corrected lens, although there is a diffusion which may indicate that the point source is not in the object plane, there is nothing to indicate which side of the object plane it is or how far it is from it.

In order to show the characteristic chromatic edges produced in the images of black and white objects, colored photographs of a black cross on a white background and of a white cross on a black background were taken with a lens having approximately the same chromatic aberration and oblique astigmatism as the eye, and also with a corrected lens. They are shown in Figures 25, 26, 27, 28, and 29. The photographs taken with the corrected lens will be considered first as they show the exact shape of the black and white crosses.

Figure 28 was taken with a corrected lens of the crosses placed at C, Figure 23. The blue, yellow and red images are seen to be all of the same size and shape, the combined image will therefore be white and black with no chromatic edges.

Figure 25 was taken with a lens having approximately the same chromatic aberration and astigmatism as the eye, of the crosses at C as in Figure 28. Being beyond both the primary and secondary astigmatic fields for blue the blue is generally diffused. Being in the secondary field for yellow the yellow horizontal or radial lines, both black and white, are relatively sharp, the vertical or tangential ones,

diffused. Being nearer the primary than the secondary field for red, the vertical lines are sharper than the horizontal ones. The chromatic edges that exist from the combined figures can be visualized by the amount the different colored edges extend in the different directions. It is regretted again that these figures cannot be reproduced in color which shows the effects much more clearly. The marked difference in characteristic edges in this figure compared with Figure 28 is however plainly evident.

Figure 29 was taken with the corrected lens of the crosses placed at B, Figure 23. A photograph of the crosses placed at D is so similar that it is not shown.

Figures 26 and 27 were taken with a lens having approximately the same chromatic and astigmatic aberrations as the eye of the crosses placed at B and D, Figure 23. The characteristic diffusion and accentuation of vertical and horizontal lines for the different colors is evident and a little study will show that it takes place in conformity with the position of the primary and secondary object astigmatic fields for the different colors.

The marked difference in characteristic imaging between these figures and Figure 29 should be noted.

In all these photographs the objects were at an angular obliquity of between eighteen and twenty degrees. If the angular obliquity had been less the characteristic imaging would be different due to the difference in the relative positions of the primary and secondary astigmatic object fields for the different colors.

SUMMARY.

The foregoing demonstrates that the retinal image of an object in space has characteristics both as to shape and colored edges due to the object's particular position in space relative to the observer and his fixation point. In other words with a given fixation the image of a particular object in the field of view has characteristics which are peculiar to the image of an object at its particular angular obliquity and distance.

That these characteristics are of sufficient magnitude to be recognized is evidenced by the fact that those doing research in this line have been able to discover and measure them. The accentuation of radial and tangential lines is observable in landscape views. This accentuation can be observed in Figure 30. Hold up the page so that you can either look by its edge at some distant object or at the small

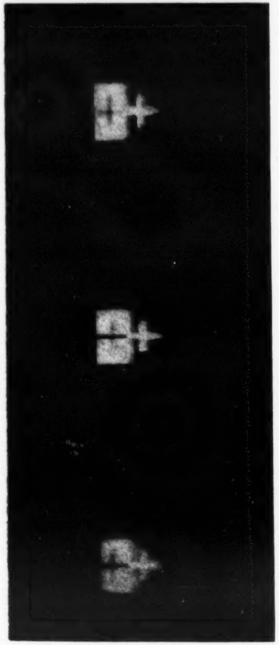


Fig. 25.

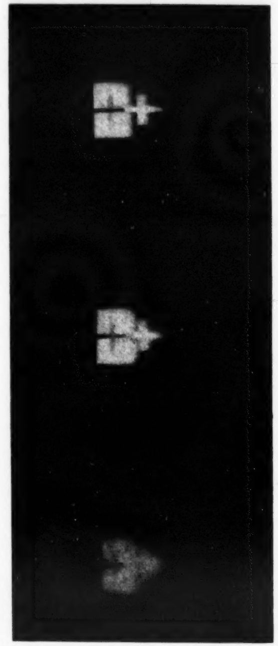


Fig. 26.

Fig. 27.

FIGURE 25. Three color photograph of black and white crosses taken with a lens having approximately the same chromatic aberration and astigmatism as the eye. The camera was focused at point marked "Fixation Point" Figure 23, the crosses were at C. Width of arms of crosses $\frac{1}{12}$ inch.

FIGURE 26. Same as Figure 25 except that crosses were positioned at B, Figure 23. Width of arms of crosses $\frac{1}{4}$ inch.

FIGURE 27. Same as Figure 25 except that crosses were positioned at D, Figure 23. Width of arms of crosses $\frac{1}{24}$ inch.

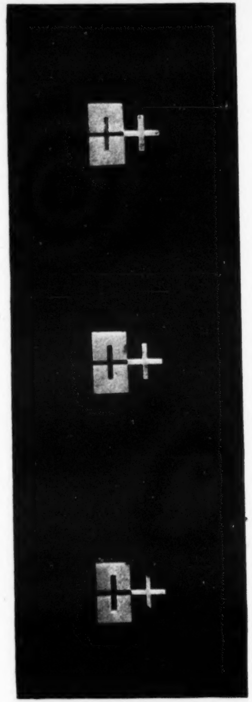
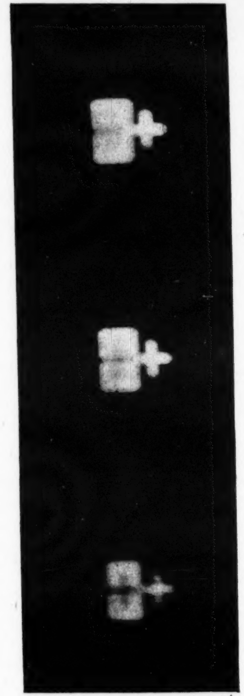


Fig. 28.



RED.

YELLOW.

BLUE.

Fig. 29.

FIGURE 28. Same as Figure 25 taken with a corrected lens.
FIGURE 29. Same as Figure 26 taken with a corrected lens

cross near the edge. If a distant object is focused the vertical line in the large cross is more evident than the horizontal line. If the little cross on the edge of the page is fixated the opposite is the case. Care must be taken not to let the accommodation or line of vision vary.

These facts lead naturally to the assumption that with a given fixation the characteristic imaging of oblique objects in space informs us of their distance; that is if an object has sharp tangential edges we judge it to be nearer than an object with soft tangential edges and if it has sharp radial edges we judge it to be farther away than an object with soft radial edges. If this is so, objects depicted in a picture with sharp tangential edges should appear nearer than those depicted with soft ones and objects depicted with sharp radial edges should appear

FIGURE 30. Figure for observing change of appearance of radial and tangential lines with variation of focus.

farther away than objects depicted with soft ones. This is exactly what was found to be the case as is shown by Figures 30a and 30b. Carefully observing 30a it will be seen that the circles with the sharp edges, whether inside or outside appear nearer than the circles with the soft edges. In Figure 30b it will be seen that the central portions of figure I which are sharp edged appear to be more distant than the circumference where the edges are soft, while in figure II where the radial edges near the center are soft and those near the outside sharp the center seems to be on the same plane as or nearer than the circumference.[8]

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8 These illusions are more apparent if one eye is closed for the reasons given in the footnote page 15.

The judgment of two hundred and two students at Dartmouth College were obtained on the effect of these illusions. On the figures in 30a 77.3% judged that the circles with the sharp edges appeared nearer than those with the soft ones. 19.8% made the opposite judgment and 2.9% got no effect.

On the figures in 30b, I and II, 82.2% judged that the central portions of Fig. I appeared more concave than that in Fig. II. 17.8% made the opposite judgment.

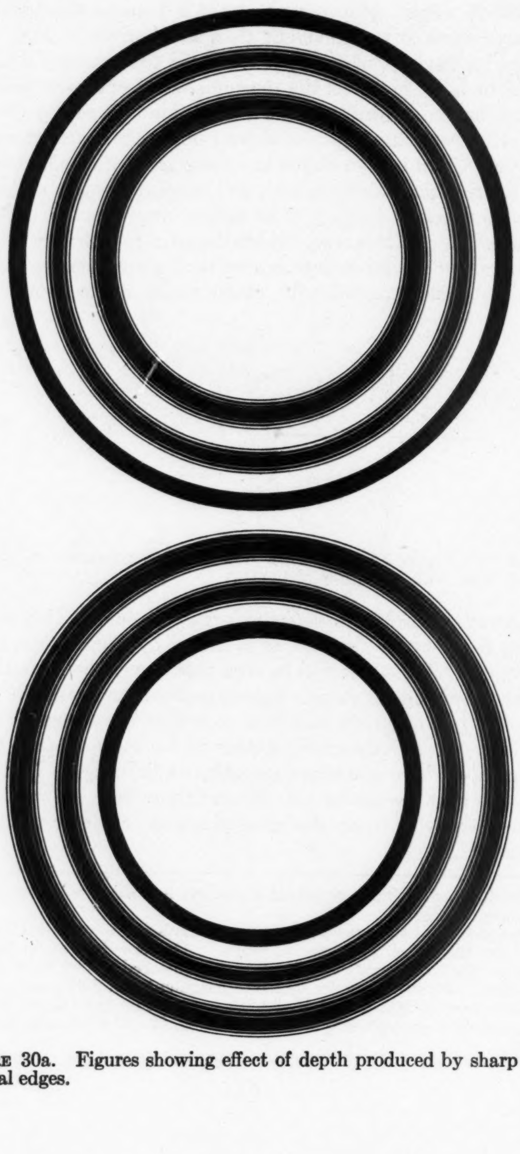
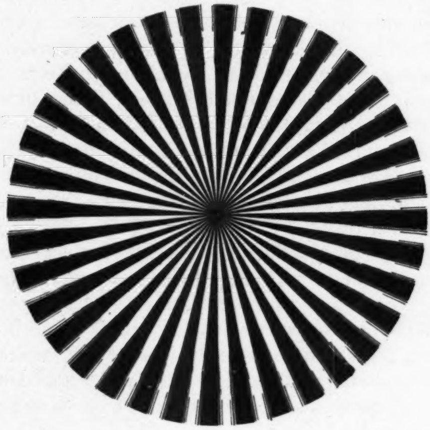
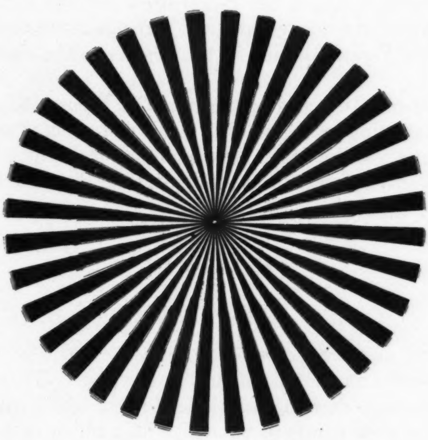


FIGURE 30a. Figures showing effect of depth produced by sharp and soft tangential edges.



I



II

FIGURE 30b. Figures showing effect of depth produced by sharp and soft radial edges.

In paintings made by Mrs. Oakes Ames in which objects on the sides of the pictures were depicted with these characteristics a marked sense of depth is given by the objects taking their proper relative distances. The accentuating of tangential and radial lines in their proper planes is found in many paintings, especially those of Turner in whose work it is apparent in the accentuation of tangential lines inside the focus and of radial lines on and behind the object plane of the scene he is painting. The accentuating of tangential lines in the foreground is found in many works of art and might be called almost a trick of composition to produce an effect of depth.

Although a large part of the above described effects are due to color and therefore cannot be reproduced in black and white, the photographs in Figures 31 a and b taken with a lens having approximately the same oblique aberrations as the eye, and 32 a and b taken with a corrected lens, are shown to give an idea of the general differences obtained. The photographs in Figure 31 a and b are believed to give a greater effect of depth and to be generally more pleasing than those in Figure 32 a and b.[9]

The accentuation of the tangential lines and softening of the radial lines in the foreground are very apparent in the candle stick in Figure 31a. The accentuation of the radial lines and the softening of the tangential lines in the background and plane of the focus are apparent in the books in Figure 31a and in the objects on the right and left of Figure 31b.

The difference in the size of the books in Figures 31a and 32a is due to the distortion in Figure 31a. This distortion is approximately the same as exists in the eye. This difference in size may help to cause Figure 31a to give a greater sense of depth than Figure 32a.

Chapter IV.

DISTORTION.

There is still another factor that affects the nature of the images of an object situated on one side of our line of vision. That is distortion. It can be defined as that characteristic of a lens which causes variation in distance between points in the image field which in the object field are equidistant. The eye is subject to so-called barrel distortion,

[9] It is regretted that the general loss of detail due to reproduction masks much of the effect which is apparent in the original photographs.

Fig. 31a.

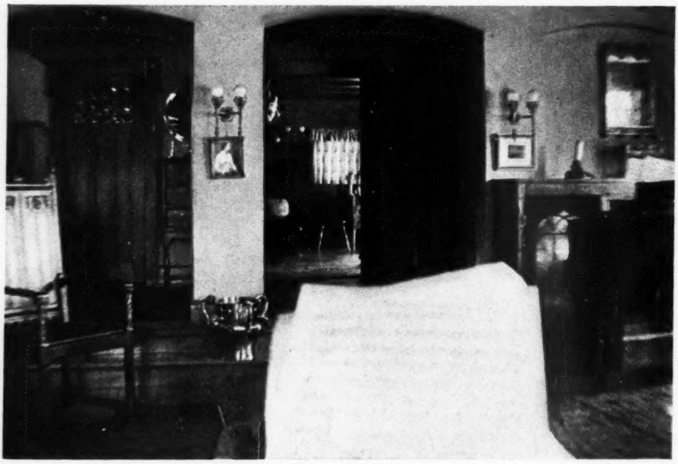


Fig. 31b.

FIGURE 31a and b. Views taken with lens having approximately the same aberrations and distortions as the eye.

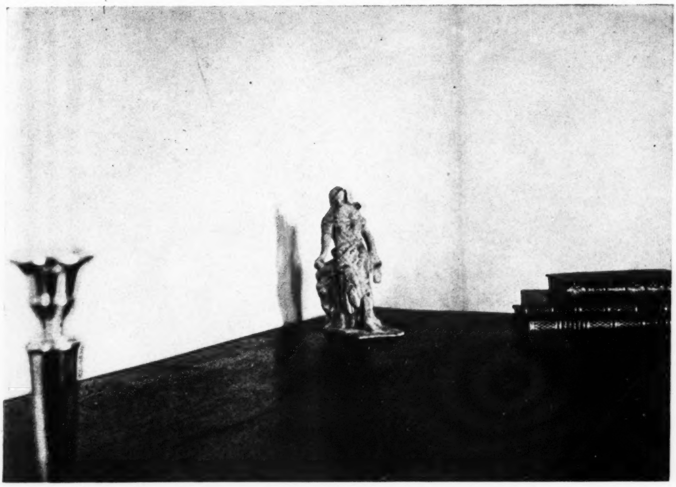


Fig. 32a.

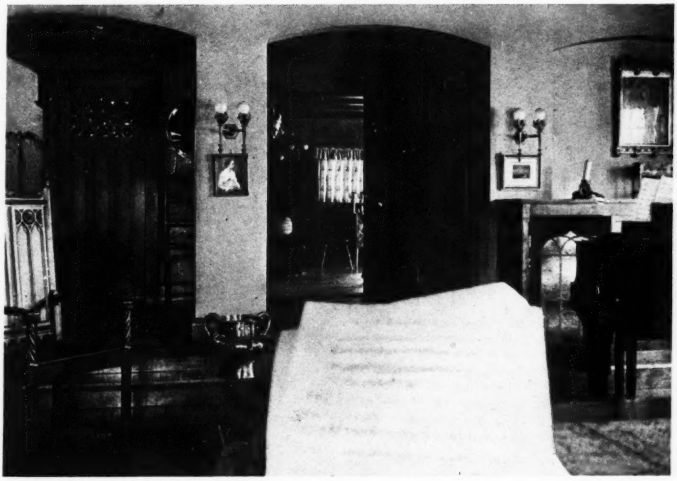


Fig. 32b.

FIGURE 32a and b. Same views as in Figure 31 taken with a corrected lens.

which means that a series of points subtending equal angles in space are not imaged at equal distances on the retina. The images of equidistant points at a distance from the axis are closer together than those near the axis, the farther from the axis the closer they are together.

Figure 33 shows the approximate distortion which exists in the eye. If the eye looks at the center of a rectilinear grid, similar to the one in the figure, held at such a distance that when looking at its center the corner will subtend an angle of thirty-two degrees with the visual axis, the picture that is formed on the retina will not be a reproduction of

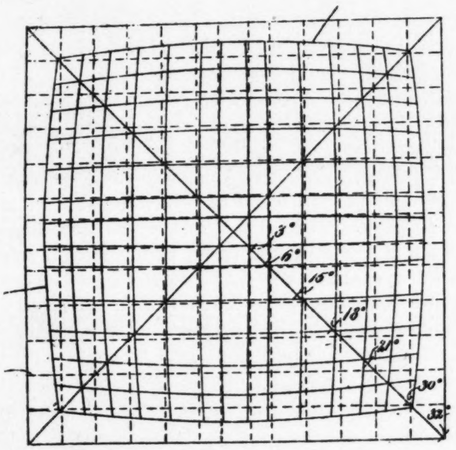


FIGURE 33. Curves showing the "barrel" distortion of a rectilinear grid that takes place in the eye.

the rectilinear grid but will take the form of the barrel shaped grid shown in Figure 33. By comparing the two grids it will be seen that points that are equidistant on the rectilinear, as shown by the intersection of the cross lines, are not equidistant in the barrel shaped grid. They are practically the same distance apart near the axis but the farther away from the axis you go the smaller these distances become.

The effect of this is twofold. It causes straight lines that do not pass through the axis of vision, to be bowed outward in their central portions. It also causes objects away from the axis to be imaged in smaller relative size than those near the axis.

This effect applies to all objects depending in amount upon their angular obliquity regardless of their distance away.

This distortion is very easily seen by looking at the middle of any rectilinearly bounded space such as the side of a room and, without allowing the axis of vision to change, noting the curvature of the boundary lines.

It is in fact the most easily noticed of the characteristics of our retinal picture.

SUMMARY.

The effect of this distortion on the nature of the images of objects off the axis is very marked. It causes straight lines in a scene to become curved and take very different positions relative to each other from those laid down by the laws of disappearing perspective. At the same time it causes objects to one side of the line of vision to become relatively smaller.

In corrected photographic lenses this distortion is corrected so that with such a lens a photograph of the rectilinear grid shown in Figure 33 would also be rectilinear with all the squares the same shape and size. Figure 34, which is a photograph taken with a lens having the same distortion as the eye, shows the characteristic barrel distortion while Figure 35 shows the same scene taken with a corrected lens. The barrel distortion is shown in Figure 34 in the curvature of the lines in the tiling, of the edge of the tank and of the balcony. This distortion produces a more natural effect. This is most noticeable by comparing the ceilings in the two photographs. That in Figure 34 seems to arch over properly, while that in Figure 35 flares upward. It is also evident in the way the lower left hand corner of the tank is rendered. By comparison the corner in Figure 35 seems to fall away and gives the effect of the water not being level.

It is of the greatest interest and significance, that of all the characteristics of the retinal picture distortion has been most commonly used by the great painters. That the "rectilinear" effect is not satisfactory has long been recognized. W. R. Ware in his book [10] on perspective in a chapter entitled "Cylindrical, Curvilinear or Panoramic Perspective" points out that the laws of ordinary disappearing perspective must be departed from in order that the depicting of certain features on the sides of the field of view shall appear satisfactory. He shows this is especially necessary in the case of certain architectural compositions,

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10 Modern Perspective, W. R. Ware, University Press, Cambridge, Mass.

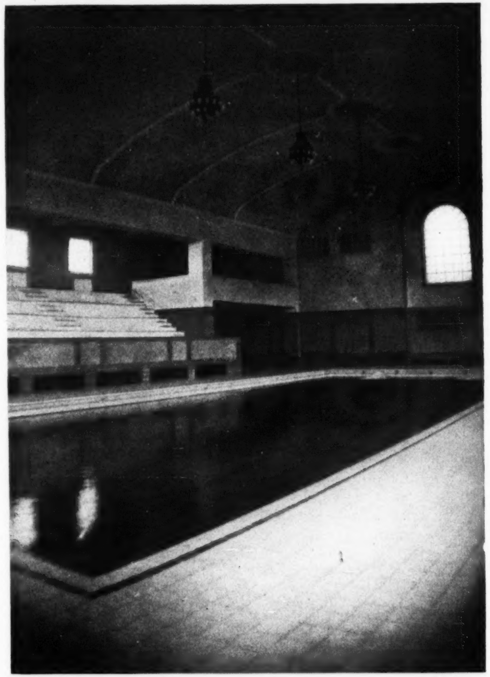

Fig 34.

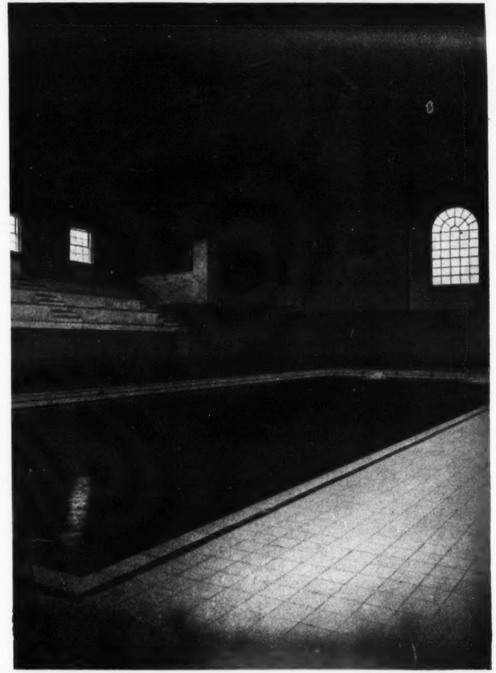

Fig. 35.

FIGURE 34. Architectural interior taken with lens having approximately same distortion as the eye.
FIGURE 35. Same view as Figure 34 taken with a corrected lens.

FIGURE 36. Copy of painting by Israels showing "barrel" distortion.

and shows further many instances where this has been done by great artists. He shows further that satisfactory results can be gotten by introducing what practically amounts to a "barrel distortion." It is not evident, however, that he recognizes the fundamental principles on which curved perspective is based.

The writers have made what can hardly be called more than a casual search and has found distortion in the following works:

Leonardo da Vinci	"Last Supper"
Puvis de Chevanne	"St. Genevieve"
Rembrandt	Numerous instances
Israels	"The Day before Parting" [11] and "The Convalescent" and other pictures
Millet	"Cliffs of Gouchy" [11]
Turner	Numerous instances
Whistler	Etching Venice Scene, "The Palaces" First Venice Set 1880
De Hoogh	"Interior of a Dutch House" [11]
Van Vleet	"Church Interior" [11]
Inness	"The Greenwood"

The lack of its consistent use in most cases causes one to believe that those who used it did so intuitively to make the picture "look right." Israels, however, used it so consistently that he probably was conscious of the law and the same is probably true of Rembrandt. The only example of it that has been found in the works of living artists is in Sir William Orpen's painting "The Peace Conference." As only a photographic copy of this picture has been seen there is a possibility that the distortion was in the photograph. Figure 36 is a reproduction of Israels's "The Day before Parting." The distortion is most evident in the tiling in the floor though it can be seen in various other parts of the picture.

One would think that the representation of straight architectural features by a curved line coming next to the straight edge of the frame of the pictures as it often does would be very noticeable. It is not however. Not that it is not perfectly evident when one's attention is called to it, but it does not attract one's attention. Its evident effect in many cases is to prevent certain parts of the picture from looking as if they were falling out.

In using distortion the detail, edges, etc., of the distorted features

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[11] These pictures are at the Boston Art Museum.

should be depicted approximately in the way they would be imaged on the retina. This was shown by the obtrusive unnatural appearance of a painting which Blanche Ames and Mr. Ames made in about 1912 in which they put in the approximate distortion which exists in the eye but painted all the detail as it appeared while looking directly at it. In later pictures painted by Blanche Ames in which the detail of the distorted features approximated in its characteristics the way it is imaged upon the retina the distortion ceases to be noticeable and gives a pleasing and natural effect.

Another interesting effect due to distortion results from the fact that objects away from the optical axis are imaged in smaller relative size than those near the axis. This effect is very evident in Figures 31(a) and 32(a). In Figure 31(a) taken with the eye lens the statuette is much larger relative to the books than it is in Figure 32(a), although the statuette in both pictures is the same size.

With a larger angular field this relative difference in size is still greater. In the eye where the field is between four and five times that in the figures the effect is very marked. This is probably the reason why a distant mountain appears so much larger to us when we look at it than it does in a photograph taken with a corrected lens.

Chapter V.

SENSITIVITY OF THE RETINA.

As stated in the introduction, the character of the picture we get on the retina is determined not only by the kind of image that is formed by the lens system of the eye but also by the nature of the sensitive surface upon which the image falls, that is by the sensitivity of the retina.

To gain a thorough knowledge of our retinal picture it is necessary therefore to know the sensitivity of the retina in its various parts both to light and to color.

Unfortunately relatively very little is known as to the sensitivity of the retina as a whole. Considerable is known about the sensitivity of the fovea, i.e., that part of the retina which is on the axis of vision, but very little definite knowledge exists as to the sensitivity of the peripheral parts.

A great deal of work has been done on the limits of the color fields, i.e., as to the limit of obliquity at which different colors are visible.

The validity of that work, however, is put in question for reasons given in the article on "Dioptrics of the Eye" [12] by Dr. Proctor and Mr. Ames.

As far as is known no quantitative measurements, with one exception which will be considered later, have been made of the color sensitivity of different parts of the retina. The late Dr. J. W. Baird and Mr. Ames undertook to make such measurements at Clark University in 1913, but found that the aberrations of the lens system of the eye would first have to be determined. This led to the work described in "Dioptrics of the Eye." Mr. Ames hopes to carry out these quantitative measurements later.

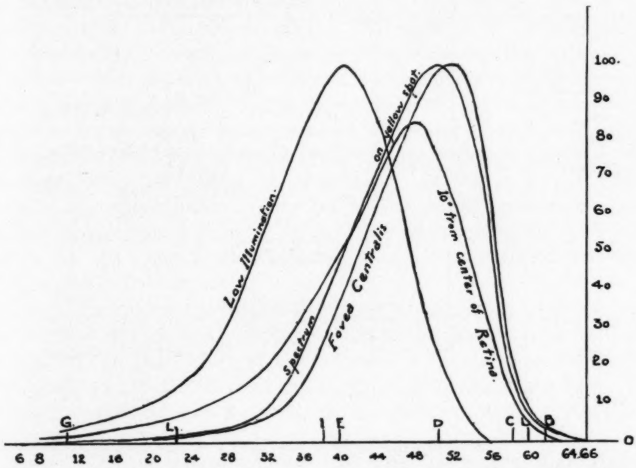

FIGURE 37. Curves showing sensitivity of the retina in various parts to light of different color.

Dr. Baird and Mr. Ames did find that blue appeared much more saturated on the periphery than it did on the fovea. This is in conformity with measurements made by Abney.[13] He measured the sensitivity of the retina to lights of different wave lengths both at the fovea and at an angle of ten degrees. His results are shown in Figure 37. It will be seen that blue appears brighter at ten degrees than at

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[12] Loco Set.
[13] "Researches in Color Vision," p. 94, Longmans Green & Co., 1913.

the fovea. The amount brighter that blue light of different wave length appears is shown in Figure 38.

This greater peripheral intensity of blue is probably primarily due not so much to the difference in sensitivity of the retina in the two regions as to the absorption of blue light at the fovea by the yellow spot. The yellow spot lies over the fovea, covering an angular area of about six degrees horizontally and four vertically. Its effect is to absorb light of short wave lengths, i.e., blue.

The effect on our retinal picture of this difference in sensitivity is to cause those parts which are outside the yellow spot to appear more

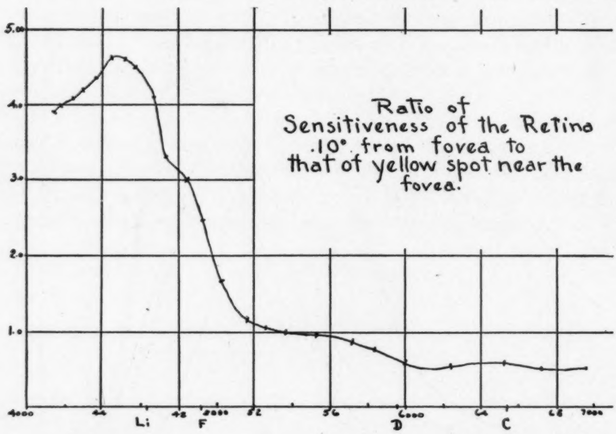

FIGURE 38. Curve showing ratio of sensitivity of the retina 10° from the fovea to that at the fovea.

blue. This effect was very evident to Dr. Proctor and Mr. Ames while measuring the astigmatic fields for blue light, the blue light appearing many times brighter when it was a few degrees off the axis than when looked at directly. The sensation is also commonly experienced in the falling off of the apparent blueness of something one sees out of the side of the eye when one turns to observe it directly.

To approximate this effect photographically a yellow spot of approximately the proper absorption and of about six degrees in angular size was put in the middle of the blue focal plane filter which with a red and green filter was used to take three color photographs. The exposure

for blue was then made sufficiently longer so that the color rendering would be normal in the center of the picture while on the outer parts the blue would be stronger in approximate accordance with the results found by Abney. A lens having the approximate aberrations and distortion of the eye was used.

The results were very interesting. The effect was two-fold; first: to render all the colors outside of the "yellow spot" bluer; second: to make more apparent the aberrations in the images formed by oblique rays and thus cause a greater softening of the outer parts of the picture. In the photographs in which the color rendering all over the picture was the same as we get in our yellow spot the aberrations of light from the blue end of the spectrum, although they existed, were so low in intensity as to produce no effect. When, however, the intensity of the blue light was made greater these aberrations became apparent.

These effects are primarily chromatic and show very poorly in black and white reproductions. The difference in the apparent aberration however is evident in the photographs shown in Figures 39a, b, and c. These were taken with a lens having the approximate aberrations of the eye. In Figure 39 (a) no filter used. In Figure 39 (b) a filter having the approximate absorption of our yellow spot covered the entire picture. In Figure 39 (c), which represents the conditions we get in our eye, a similar filter covered an angular area corresponding to that of the yellow spot.

It will be seen that the whole of the picture in Figure 39 (a) is much softer than that in 39 (b). This is due to the greater amount of the aberrated blue light which struck the plate in Figure 39 (a) and which is absorbed by the filter used in taking 39 (b). In Figure 39 (c) the center portions are sharp due to the local action of the yellow filter while the outer part is soft due to its absence. It is very evident that Figure 39 (c) which approximates the conditions we get on our retina is much more pleasing[14] than Figure 39 (a) or 39 (b). Figure 39 (d) is a photograph of the same scene taken with a corrected lens. This seems to be pretty conclusive evidence that the purpose of the yellow spot is to counteract the strong chromatic aberration in the eye by reducing the brightness of the light from the blue end of the spectrum so that it ceases to be apparent.

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14 It is regretted that a very marked effect that is apparent in the original photograph is lost in the reproductions.

SUMMARY.

The above facts show the marked effect that variations in sensitivity of the retina have on the nature of our retinal picture.

The slightly brighter warmer centers in some of Corot's pictures suggest the effect produced by the yellow spot. But besides his work the only evidence that has been found that the above described effects have been made use of by artists is in their very common practice of rendering shadows in out-of-door scenes much bluer than they appear when one looks directly at them. As far as is known this has not been limited to the outer parts of their pictures. The blue appearance of shadows which are imaged on the side of the retina are, however, very easily seen, and as this effect holds true over the greater part of the field of vision it was probably found that pictures look better with blue shadows all over them than without any blue shadows at all.

As has been stated our knowledge of the sensitivity of the retina is very limited. We already know, however, that our capacity to distinguish detail away from the center of focus is largely due to the structure of the retina. It is probable that a further knowledge would give suggestions as to the laws which control the difference of local values of which we are conscious on the different parts of the retina.

There are also of course other effects such as contrast, simultaneous and successive, and after images which must have a marked influence on our retinal picture. Their use in pictures raises the thought of the possibility of suggesting eye motion.

Chapter VI.

BINOCULAR VISION.

The fundamental idea in undertaking the research work which is the basis of this article was that pictorial art should be similar to our mental visual images, and, since our mental visual images are probably similar to our retinal pictures, valuable suggestions could be obtained from a knowledge of the characteristics of our retinal picture. Our mental visual impression, however, is not derived from a single retinal picture but from two, as we normally look with two eyes.

The whole subject of binocular vision is too long and complicated to be considered here. It was believed, however, that some of the characteristics of binocular vision under particular conditions could be reproduced in a single picture such as a photograph or painting.

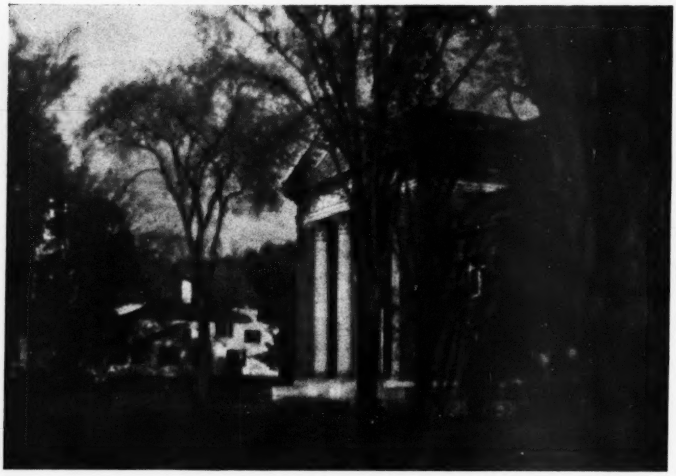

FIGURE 39a. View taken with a lens having the same chromatic aberration as the eye.

FIGURE 39b. Same view as in 39a taken with lens having the same chromatic aberration as the eye and a focal plane filter having the approximate absorption of the "yellow spot" covering the whole picture.

FIGURE 39c. Same as 39b. The focal plane filter covering the area covered by yellow spot thus approximating the conditions we get in one eye.

FIGURE 39d. Same view taken with a corrected lens and no filter.

Fig. 41.

Fig. 42.

FIGURE 41. "Binocular" photograph.
FIGURE 42. Same view as in Figure 41 "monocular" photograph.

The conditions chosen were where the background behind the object at the point of convergence was of an indeterminate nature such as a mass of branches or foliage. The absence of any marked contours under such conditions would not call for the suppression of parts of either retinal image.

Leaving out the effect of ocular movement and the fusion of doubled images the brain under such conditions may be considered as receiving two superimposed pictures of the object field as seen from each eye.

To reproduce this effect a camera was devised which, by means of a reflector and half silvered prism, produced superimposed pictures of the landscape as viewed from two points of view,— the distance between which was the same as that between the eyes. The detail in these pictures superimposed where the axis of the two systems crossed, as the two monocular images do at the point of convergence. The details in all other parts of the pictures were more or less doubled due to the parallax of the two systems.

Figure 41 shows such a "binocular" photograph. Figure 42 shows an ordinary photograph of the same scene.

The following characteristics will be noted in the "binocular" picture:

First, there is a "broadening" of everything in a horizontal direction. At the convergence point this is due to seeing more of the sides of an object. At other points in the scene it is due to the doubling in a horizontal direction resulting from the parallax. This effect of the "broadening" of a scene when viewed binocularly can be noticed by anyone by first observing the scene with one eye and then with two.

Second, there is an increase in contrast values between the lights and darks in the objects at the convergence point relative to that in other parts of the picture. This is due to the fact that at the convergence point the darks and lights superimpose and so reinforce each other while in all other parts of the picture they tend not to superimpose and so counteract each other. Probably some such effect as this exists in our binocular impression.

Third, there is a doubling up of the images of objects not at the convergence point, the extent of the separation of the doubled images depending upon their distance from that point. The seeing of objects not at the convergence point in doubled images is supposed to be one of the factors that gives us our idea of relief, the extent of the doubling suggesting the distance of the object from the convergence point. The impression we receive on our mind from these doubled images is different from that shown in Figure 41 due to the modifying effects of the

antagonism of the visual fields which suppresses one set of images, and to other physiological factors. Our impression, however, is probably more like the effects shown in Figure 41 than like a monocular impression, as is shown by the greater effect of depth, less flat appearance of Figure 41 as compared with Figure 42.

SUMMARY.

It is well known among artists that a different effect is produced from painting with one eye than with two and that to get satisfactory results two eyes must be used. There are unquestionably certain effects in the binocular impression that can be reproduced in a single photograph and still further effects that can be reproduced in a painting, where factors such as antagonism of the visual fields can be dealt with. There are other effects due to ocular movements which cannot be reproduced in a single picture but which may be possible of reproduction in motion pictures.

Chapter VII.

GENERAL SUMMARY AND DISCUSSION OF RESULTS.

From the foregoing description of the characteristics of retinal images of objects in various parts of the visual field it is possible to determine fairly definitely the nature of the retinal picture as a whole. It can be described, in general terms, as being a picture in which objects at the center of interest, or focus point, are depicted in considerable detail, but not with microscopic detail.

Objects in the field of view, nearer or farther from the observer than the center of interest, are depicted with less detail and with chromatic edges the color of which depends upon the position of the objects relative to the center of interest.

Objects lying to one side of the line of vision are also less clearly depicted, the lack of clearness increasing with the angle of obliquity, the accentuation of detail and edges in such objects depending upon their position relative to the center of interest. Speaking generally this accentuation is in a tangential direction if the objects are situated nearer to the observer than the center of interest and in a radial direction if they are on the plane with or behind it. Such oblique objects also have characteristic chromatic edges depending upon their position relative to the center of interest.

All oblique objects are distorted and changed in shape varying in amount with their obliquity. This distortion is shown in the bowing out in their central portions of straight lines which do not pass through the center of interest and a reduction in size of oblique objects.

And finally the color of the picture in its outer parts is bluer than at its center.

In our ordinary habit of vision, when looking at a scene, we focus on some particular part or object in it due to its special interest or beauty to us; we hold that focus for a moment or two and then look at another center of interest or another or look away entirely. With each fixation of the eye a retinal picture of the kind just described is formed. We therefore receive on our retinas a series of such pictures.

MENTAL VISUAL IMAGES.

The question arises: What is the nature of the mental visual images which we have of actuality? Without doubt, our brain receives a series of impressions similar in character to our retinal pictures. But how are those impressions registered in our consciousness and memory. There are two general possibilities. One that our visual memory consists of a series of pictures similar in nature to our retinal pictures. The other that, by some mental process, these serial impressions are combined and form a memory impression similar to actuality as we know it exists intellectually, i.e., with the detail all over the picture sharp and clear and with no colored edges or distortion.

Although there is no known psychological work on the analysis of mental visual images to substantiate the conclusion, what evidence there is indicates that our mental visual images consist of a series of images similar to our retinal pictures. This was the opinion of the well known psychologist, Dr. J. W. Baird, who mentioned as a reason for such belief the relatively definite character of the center and nebulous character of the outer parts of our mental visual images both when we are awake and when we are dreaming. Such a view is further substantiated by the fact that the indefiniteness in those parts of a scene that are not at the focus point and other characteristics of our retinal picture give a sense of depth and relief. A sacrifice of these characteristics would mean a sacrifice of effect of depth in our mental visual images which would seem most improbable.

Furthermore the existence of a mental visual image of a scene similar in detail to the scene itself could only be based on a visual knowledge of all the detail in the scene. This could only be acquired by passing

the fovea or clear seeing part of the eye over every part of the scene which of course, is never done in the ordinary habits of vision. It also assumes some process of mental synthesis of particular parts of a series of impressions; of the existence of such a process we have no evidence.

It is believed that it can be concluded that our mental visual images of actuality consist of a series of images similar in general character to the picture we receive on our retina, or more accurately a series of combined pictures such as we receive on our two retinas.

METHODS OF DEPICTING NATURE.

In the arts, painting, drawing, sculpture, photography, our purpose is to depict nature. There are in general two ways in which this can be done.

First, a reproduction of the actuality can be attempted. By this is meant as close a reproduction as possible of all the objects in the scene in every measurement and detail. In sculpture the well known wax figures do this most successfully, though much work in marble and clay does so very closely. In the pictorial arts it has been most closely approximated by photographs taken with a corrected lens. Many paintings in which all objects have been depicted in full detail, as they appear on the fovea of the eye when directly observed, also very closely approximate actuality. By this is meant that the objects are so placed in the picture and the details of the objects are so depicted that, if the picture is viewed from the proper distance, all the objects will lie in the same angular direction as they do in the scene itself; while the depicting of each object is such as to produce to the eye looking directly at it the same appearance that the object itself would produce were the eye looking directly at it.

In a photograph this is accomplished by using a corrected lens; that is, one which has been so designed and constructed that every object in the field is imaged with as great detail as possible and the images of objects in the image plane have the same relative lateral positions to each other as the objects themselves. The same result is accomplished in a painting or drawing in which the artist depicts every part of the scene as it appears to him while looking directly at it. Every object will then be represented in full detail whether near, far, or on one side of the field of view, and the depicted objects will lie in the same relative lateral positions to each other as the objects themselves.

While such representations of nature are a reproduction of actuality in the accuracy with which the detail and relative lateral positions of

objects are depicted, they do not reproduce the positioning of objects situated at different distances. This is impossible because a picture is, of necessity, on a flat surface where everything depicted must be the same distance from the observer, whereas nature exists in tri-dimensional space.[15] Due to this fact, the picture as a whole can never give the same effect to one looking at it as one gets from looking at nature. For in looking at one part of a natural scene, objects at all other distances take on characteristic appearances due to their different distances. In a picture where they are all reduced to one plane this is not true.

The second way in which the depicting of nature can be attempted is, instead of trying to reproduce actuality itself, to attempt to reproduce the impression that nature makes on the human consciousness, i.e., to reproduce mental visual images. The general characteristics of our mental visual images are, as it is believed it has been shown, similar to those of the retinal pictures.

Such depicting of nature can be approximated photographically by means of a lens which produces the same characteristic imaging as the lens system of the eye, and a plate whose sensitivity over its various parts is similar to that of the retina. It can be approximated in paintings and drawings if the artist keeps focused on whatever he picks out as the center of interest and depicts everything else as it appears to him while keeping his eye focused on that point. Artists who have very clear and lasting mental visual images closely approximate it by copying those images directly without regard to actuality.

As the retinal picture lies on a surface and as the canvas or paper on which it is depicted is also a plane surface, there does not seem to be the same fundamental limitations in reproducing it that exists in attempting to reproduce tri-dimensional actuality. In reproducing the subjective binocular impression in a single picture there do exist, however, the limitations which arise from the impossibility of reproducing those parts of the impression which we get from eye movement and motor impulses.

For all artistic purposes, it is believed that the attempt should be to reproduce not the actuality but the impression which it makes on us. Three general facts may be given in support of this.

First, the use by so many of the great painters of characteristics of the retinal picture which is the strongest evidence of the artistic value

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15 Stereoscopic photographs do reproduce the effect of the third dimension. They are not however satisfactory from an artistic point of view, and as we are dealing only with single pictures will not be considered here.

of pictures of this type. Second, photographs taken with a lens which approximately reproduces the characteristics of the retinal picture are more pleasing than those taken with a corrected lens. Third, photographs taken with corrected lenses are the most perfect reproduction of actuality which we have, much more accurate than can probably ever be accomplished with brush or pencil, yet this type of picture is admittedly a complete failure from an artistic point of view, indeed its failure seems to be due to the fact that it does reproduce actuality so accurately.

The following three argumentative reasons are also given:

First, the general accepted belief that artistic expressions are subjective. The purpose of the great artist is to make others see nature as he sees it. He could convey no more by reproducing actuality to those who look at his picture than they would get by looking at the scene itself. He has to put into his picture nature's impression on himself, the beauty and the truth he sees. Second, the subtle variations and differences which cause him to see the scene beautifully are alterations in his mental visual images due to personal psychological factors. The depicting of such subtle differences could be much more easily accomplished in a picture which in its general type was similar to his subjective impression than one which was not. Third, the purpose of art is to awaken subjective associative processes in those who look at it. This is especially evident in portraiture. The natural way to cause us to recall our mental visual images or start a train of them in motion is to present to us a picture similar to them.

When we look at a picture of this type we recognize that it is an attempt to reproduce not actuality but our impression of actuality. Where we see the objects farther away than the object in focus depicted without much detail we do not think that they in fact did not have detail in them or perhaps that an intervening mist existed which obscured the detail but we know that such objects were farther away than the object in focus. And similarly with the distortion of line on the side of the field of view, we do not think that a building, for instance, so depicted is in fact curved. We recognize that such is the character of our subjective impression of a building on one side of our field of view. That is we pass our fovea or the part of our eye that gives us distinct vision over the picture and recognize its various parts as being similar to our mental visual image, just as we can direct our attention to various parts of such an image.

There is possibly a third way to attempt to depict nature, which may be considered a modification of the first method above described.

In such a picture, all objects not at the center of interest would be painted so that, when the center of interest in the picture was looked at, the picture as a whole would make an impression similar to that produced by the scene itself. Such pictures as photographs taken with corrected lenses attempt to do this but, as has been stated, fail in that they do not give a proper suggestion of depth.

In this third type this deficiency might be met by accentuating the characteristic imaging of all objects not at the focus point to suggest their position in tri-dimensional space. For instance, near dark objects, in the line of focus, would be shown with red edges, distant ones with blue; and, on the sides of the picture, the radial accentuation of distant objects and the tangential accentuation of near objects would be shown.

In making these peripheral accentuations it would have to be borne in mind that they would be modified by the oblique aberrations of the eye as they would lie on the peripheral part of the picture and be imaged on the periphery of the retina. Allowances would therefore have to be made. As the picture plane lies near the secondary astigmatic field the radial accentuations would have to be relatively slight and tangential accentuations relatively marked. No distortion would be put in such a picture as the eye itself would introduce it, if the picture was viewed from the proper distance.

Granting that the proper accentuation of the radial and tangential and chromatic edges could be made, which would be very difficult, it is questioned whether such a picture would be satisfactory.

The proper impression could only be produced when the center of interest of the picture was looked at. If any other part of the picture was looked at that part would not only appear like nothing ever seen before but the rest of the picture would then cease to produce the proper impression.

THE RETINAL PICTURES AND ARTISTIC PHOTOGRAPHY.

As has been stated cameras in their inception were copied after the eye. It can be argued that the value of photographs for pictorial purposes rests on two quite different bases. One that it lies in reproducing in black and white, or in photographs in color, the same general picture we get on our retina. The other that it lies in reproducing in light and shade detail and color the effects that exist in nature.

On the first basis it can be said that the results, when looked at, are satisfactory because they appear to us similar to the impression we

have received. On the second basis it can be said they are satisfactory because in looking at them our eye is affected in the same way as it is affected by nature.

In spite of the inherent impossibility already pointed out that the effect of objects in tridimensional space cannot be reproduced on a flat surface, it seems to have been the second basis that was followed in the evolution of the art of photography. This led to the development of corrected lenses which would image everything in the field of view in full detail with no distortion.

After such lenses had been perfected it was found that the photographs taken with them, although having unquestioned value for scientific and other purposes, were not satisfactory from an artistic point of view.

Then followed the use of so called "soft focus" lenses, and various manipulations in printing and enlarging to get away from the hard full detail effect produced by corrected lenses. Those desiring artistic effects bought up old lenses such as were used in making daguerreotypes and had lenses designed in which various aberrations were left uncorrected. As a result there has of late years been a most marked advance in the artistic side of photography.

The method of development has however been one of "cut and try" and as far as is known, with the exception of the work done by Gleichen mentioned above, no fundamental laws have been followed. Innumerable methods and lenses have been tried and only those producing pleasing effects have survived.

It is believed that the advance in artistic effect has been due to the fact that the results obtained were more similar to the subjective impression and that future developments in photography on the artistic side will come from approximating as closely as possible the retinal pictures and mental visual images.

THE RETINAL PICTURES AS THE BASIS OF THE TECHNIQUE OF ART.

In the chapters describing the characteristics of retinal images of objects situated in different parts of the field of view examples were given of paintings by artists in which these characteristics appear. The lists do not mention a far greater number of works that are in general suggestive of the retinal picture without showing the special characteristics noted. Of these Corot is the best example. Whistler, Manchini and Abbot Thayer and many others are also examples.

This similarity to the retinal picture is shown in a tendency to accentuate the center of interest and lose detail elsewhere. This is especially evident in black and white work and in etchings. An explanation of this may be that it is easier to accomplish in black and white work. For in that part of the picture where it is desired to lose detail, detail is simply left out, the white paper suggesting blankness. Where color is used this cannot be done. Some color must be put on the canvas and then the difficulty arises of getting on the right colors in the right way.

It is believed that anyone going through a gallery, with the points of views here set forth in mind, will be impressed by the fact that the works of many of the best men show a suppression of detail in those parts of the pictures which are not the center of interest. And there will not be the slightest question that, in most cases, the entire picture is not painted as it would appear if every part of the scene were looked at directly.

It is also very interesting to note that it is almost a general rule that the early work of most of the great masters was, so to speak, tight and hard, photographic. There is a very good example of this in an early picture by Corot in the Boston Art Museum. Later their style or technique changes. Their work is done more broadly especially the outer parts and their pictures get a center of focus and, to use a stock term, compose.

It cannot be questioned that the change is a departure from a photographic reproduction of the scene. But the question may still remain: what are the laws that govern this change in style or technique? The commonly accepted belief is that, if there are any laws, they are purely aesthetic or psychical, and that the artist puts in and leaves out and changes solely according to the dictates of his personal taste. In view of what has been shown, especially the use by so many great painters of distortion, see Chapter IV, it is believed that the improvement in technique of these artists was due to a development of their vision. Consciously or unconsciously they approximated the scene as it would have appeared to them had they kept their focus upon the center of interest.

The difficulty which arises in this method of painting is to know how to reproduce the impression that one gets from an object at which one is not looking. That the capacity to recognize and analyze such impressions can be developed is shown by fact that some of the characteristics of such impressions have been represented by numerous artists. That this is very difficult is shown by the fact with all the

genius we must attribute to the great artists, there is, it is believed, no artist who has intuitively recognized and depicted all the characteristics above mentioned; and in spite of the fact that distortion, the most apparent of these characteristics, has in the past been used by many great artists it has been recognized and used as far as the writers know by but one artist living today, i.e., Sir William Orpen.

In fact so little do we know as to what we see that the ordinary person, including art students and many painters, do not know that we see clearly only those objects upon which we focus. They believe that the whole of the field of view is clear because when they are interested in the question of the clarity of any part of it they look directly at it and are unconscious of the eye movement.

Granting that it is desirable for the painter to be able to recognize and depict the character of his retinal impression it is believed that there is no question but that he can be greatly helped by an intellectual knowledge of the characteristics of his retinal picture. The knowledge that he never sees the whole of the scene with equal clearness will, after he has tried a few times, awaken his consciousness to the fact that he sees objects away from the center of focus less clearly. The knowledge that the characteristic edges and shapes of those objects not at the center of interest can be seen only if the eye is kept focused on the center of interest will enable him to see these characteristics. The knowledge of distortion and the perception following therefrom will cause him to become conscious of its existence. Similarly the knowledge of the characteristic chromatic edges of objects nearer and farther than the focus point, of the accentuation of radial and tangential lines and of the greater brightness of blue at a slight obliquity will lead to his conscious perception of these phenomena. Apart from the matter of developing his perceptions, the knowledge of the characteristic imaging of objects in various parts of the field of view will enable him to produce an effect of depth without the use of, or to supplement, the means now used. It will also enable him to produce a natural center of interest.

The objection has been raised that such an intellectual knowledge would be harmful to an artist by destroying the "innocence" of his eye. That is in his knowledge of and expectation of seeing these things, he would see them where they do not exist, or would over-accentuate them. If the eye were "innocent" in the first place such an objection might have weight. But it is not. Take for instance the matter of the detail which we see in objects. We know that all objects both those in focus and those nearer and farther are sharp and

clear, so we think we see them sharp and clear while in fact we see the objects out of focus with fuzzy edges.

And likewise in the matter of distortion. We know that the side of a building is straight. That knowledge destroys the innocence of our vision and makes us think we see it straight out the side of our eye when in fact we see it curved. "Innocence" is already gone. To restore truth to the eye, we have to learn that under certain conditions we see chromatic edges on objects which are in fact sharp and curved lines in place of straight ones. The same line of argument applies to the other characteristics of the retinal pictures.

The development of art seems to have been a struggle to put down what we see and not what we know or think we see. The Egyptians for instance in drawing an eye as seen from in front on a face in profile were putting down not what they saw but what they knew. So they put in the same picture what they saw from two different points of view. We are confident that today we paint things as we see them. But on consideration are we not making just as bad a mistake when we paint an object in the foreground and one in the distance with equal clarity, or when we paint straight lines on the side of the picture straight. It is just as impossible for us to see both near and distant objects equally sharp at the same time or to see straight lines on the side of our field of view as straight, as it was for the Egyptian to see the eye from the front view in the face from the side view.

The conclusion must be that the "innocence" of vision can be developed by intellectual suggestions. Such suggestions which help the artist to know what he sees will also bring within the grasp of his intellectual consciousness, so that he can definitely perceive it, what formerly he could only feel intuitively and will leave his intuition free to reach out for the subtler expression of truth and beauty.

In the ultimate analysis what the great artist expresses through his work is a matter of his own mental and spiritual visual images of beauty and truth. Their character depends upon his personality and psychology. Of necessity these factors will modify the characteristics of his retinal pictures, to what extent it is impossible of course to say. It is believed however that the technical structure of his work is based upon his retinal impressions. The similarity of his retinal image to those of the rest of mankind will insure a universality of understanding and appreciation.

It should be clearly understood that it is not suggested that the methods of depicting the various parts of a scene which have been described will in themselves make a great work of art. They are

simply matters of technique, the grammar so to speak of the expression. The quality that makes a great work of art is what the artist expresses through his work. Masterpieces expressing great truth and beauties have been done with entirely different bases of technique, the work of the "Primitives" as compared with that of the Barbizon School, for instance. Genius will express itself through any technique, but certain techniques will give greater possibilities for depth and subtlety of expression than others just as a modern piano, or violin or full orchestra gives the musical composer more freedom than the shepherd's pipes.

It is believed that everything that has been said applies to scuplture as well as to painting, taking into consideration of course that sculpture is tridimensional.

Its usefulness in architectural drawings seems to be pretty conclusively proved by Figures 34 and 35. As to its application to architecture itself, the writers do not feel qualified to speak. The belief that it is applicable can only be based on the assumption that in architecture we desire a subjective impression of a preconceived rectilinear arrangement. It would seem that under certain circumstances this might be desirable. The possibility immediately comes to one's mind that there may be a connection between the curves in Greek and Gothic architecture and the characteristics of our retinal image.

Before closing it might be interesting to suggest a line of thought to which the determination of the more specific characteristics of our retinal pictures might lead. In the first place the characteristics of our retinal pictures are greatly affected by external physical conditions. Take for instance retinal pictures of a scene in the day time and at night. Due to the enlarged pupil with which the night scene would be viewed and the greater sensitivity of the retina to blue light, as shown by the left hand curve in Figure 37, the characteristics of our retinal picture of the night scene will be very different from those of the day scene. It is believed that there is no doubt that pictures depicting these characteristics would most strongly suggest the external physical conditions which give rise to them. Further, the eye is a most delicately sensitive organ and is without doubt, affected by our bodily and likewise by our grosser emotional states. It is conceivable that the characteristics of our retinal pictures are also affected, and that specific bodily and emotional states are accompanied by specific changes in the characteristics of our retinal pictures. This in turn opens up the possibility that if the characteristics produced by a particular bodily or emotional state were depicted in a picture, the picture would suggest that particular state to those looking at it.

CONCLUSIONS.

1. Every object in space is imaged on the retina with characteristics of form, color, accentuation of line and chromatic edges, due to its particular position relative to the focus point.
2. These characteristics, of which the observer may or may not be conscious, suggest to him the position of the object in space relative to his fixation point.
3. The reproduction in a picture of these characteristics of images of objects causes the depicted objects to appear in the same relative positions that they occupied in space.
4. A pictorial representation of nature to be technically satisfactory from an artistic point of view should be similar to our subjective impression. It should not attempt to reproduce actuality.
5. Our subjective impressions are, in their general character, similar to the pictures we receive on our retinas while holding one center of focus.
6. A pictorial representation of nature to be technically satisfactory from an artistic point of view should be similar in its general characteristics to the pictures we receive on our retinas while holding one center of focus.
7. An intellectual knowledge of the characteristics of the retinal image of objects not at the center of focus helps one to become visually conscious of such characteristics.

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